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A Slab in the Face: Building Quality and Neighborhood Effects

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Abstract

The quality of newly constructed single-family houses is usually homogeneous in and heterogeneous between neighborhoods. Such quality-clustering will be caused by the variation of natural amenities throughout a suburban area. Clustering will be enforced if the quality of neighboring buildings increases the value of newly constructed ones. To disentangle the natural amenity effect and the neighborhood effect, we use data from Berlin and exploit that the endogenous effect was weakened during the socialist period. Our results show that the exogenous variation caused by buildings constructed during this period still causes lower quality new buildings in the East of the city.

Keywords: housing supply, housing externality, natural experiment

JEL Classification: R31, D62, C31

1 Introduction

Everyone who has lived in a single-family house neighborhood knows that neighbors care not only about the appearance of their own house but also value tidy sidewalks, nice gardens, and appealing building facades. There is no pleasure to be gained from looking out of one's house onto a run-down building or a park littered with waste. In economists' parlance, the quality of natural amenities and surrounding buildings are positive externalities, generating a benefit to those consuming them. Whereas it is hard to imagine that a building's physical quality should have no effect on the wellbeing of those living next to it, disagreement might exist regarding the importance of this effect (Mills, 1979, pp. 528). It is also important to understand if households just consume the quality of neighboring buildings or if households' investment in the physical quality of their own houses is affected too.

In a recent paper, Rossi-Hansberg et al. (2010) examined the magnitude of housing externalities. Using data from a housing revitalization programme in Richmond, Virginia, they established that the programme increased land values over a period of six years by 12 to 35 percent (depending on the targeted neighborhood). This provides empirical evidence for positive externalities. Their paper does not examine, however, whether the increase in land values is caused by the improvements of the targeted buildings alone or if it is further enforced (weakened) by an endogenous feedback effect where non-targeted landowners alter investments in their buildings too. In particular, their paper does not answer if we should expect building improvements between neighbors to be complements or substitutes.[1]

In this paper, we use data from Germany's capital Berlin to examine if an endogenous feedback effect between the quality of neighboring buildings exists. We

[1] Ioannides and Zabel (2003, 2008) provide empirical evidence that a household's housing demand depends positively on the mean housing demand of its neighbors. This is consistent with a complementary effect where individual households' maintenance decisions are affected by the maintenance choices of their neighbors.

exploit that Berlin was divided between 1949-1989 into two halves with different economic-political systems. The east half was the capital of the centrally-planned socialistic German Democratic Republic (GDR); the west half, lying completely in GDR territory, was a state of the market-based Federal Republic of Germany (FRG). Between 1961-1989, the city was divided physically by the Berlin Wall, which was erected by the socialistic regime to prevent its citizens from leaving the GDR.[2] All linkages between Berlin's west and east halves were cut. Figure 1 shows a map of the city, outlining the east and the west halves. In 1989, the GDR collapsed and the Berlin Wall fell. A year later, Germany was reunified and Berlin became united again.

Usually, the circular causation inherent in urban development makes it impossible to detect if the quality of buildings have an effect on each other. The natural experiment of Berlin's division provides the exogenous variation needed to detect such an endogenous effect. With Berlin's boundaries set in 1920 and amenities such as parks, lakes, forests, and transportation network in place well before 1948, the built environment received differential treatment in the centrally-planned east and the market-based west half during the 1949-1989 period. After the reunification, building construction is carried out again by profit-maximizing developers. If quality matters, then buildings constructed in Berlin's east half during the division should impact on the quality of newly constructed buildings.

This identification strategy requires that the quality of buildings in the east half constructed during the treatment period was determined exogenously. As we will discuss in detail in Section 2, building construction between 1949-1989 in the east half followed principles different from those in any other period. Instead of relying on market participants' profit-maximizing behavior, encouraged by strong private property rights, the socialist regime relied on authoritarian planning, price restrictions and curtailing of private ownership (Bernhardt, 2005, p. 106). This

[2]The construction of the Wall included the demolition of buildings close to it and the set up of the infamous "death strip".

institutional framework affected, particularly in later years of the treatment period, the quality of the building stock. The GDR did not have the economic resources to maintain buildings and construct new buildings to the same standard as it was possible in the market-based west half. The quality of newly-constructed buildings was mainly determined by the availability of construction materials and personal networks of prospective owners.

It is clear that the physical appearance of the city changed in both halves of the city during the period 1949-1989, in particular in inner-city districts, where buildings destroyed during the war had to be replaced and new means of transportation had to be accommodated.[3] However, only in the west half was this process intermediated by the market. Therefore, the setting of the treated east half and the untreated west half of the city corresponds to a natural experiment with a 'before and after design with an untreated comparison group' (Meyer, 1995, 3.2). We exploit this setting in our empirical analysis.

We use a non-cooperative externality model to understand the role amenities can play for the quality of newly-built houses. Our model shares features with the models of Philippi and Luenberger (1977) on the upkeep of rental tenements, Schall (1976) on urban renewal, and Strange (1992) on spatial density. Our model distinguishes explicitly between given natural and built amenities and the endogenous quality of buildings. The model leads to three testable implications. First, if the level of a given amenity is a positive externality, land prices should be positively related to it. This prediction holds irrespectively of whether or not the quality of buildings is endogenous. Second, if natural amenities affect households' marginal willingness to pay for quality, then buildings will be clustered by quality. Third, if the quality of buildings is endogenous, the impact of local natural amenities will be enforced (weakened) further if the quality of neighboring buildings are complements (substitutes) for each other.

[3]Such as inner city highways ('Stadtautobahn') and Tegel Airport in the west half of Berlin.

Our empirical analysis uses information on transactions of single-family houses and undeveloped residential land that occurred between 1996-2008. The buildings of the single-family houses cover all of the three different periods of Berlin's recent history. Using the nonparametric method of Bajari and Benkard (2005), we compute an index of the building quality for each house transaction. The index controls for physical deprecation and structural characteristics and reflects a building's quality as perceived by the buyers and sellers active in the Berlin single-family house market.

We test the first implication of the model by running linear regressions of land prices on an ordinal summary measure of local amenities. We find that prices of undeveloped land increase significantly with the measured level of amenity quality. This confirms that prices of developable residential land are positively related to amenities. Regarding the second implication, we examine the spatial autocorrelation of the building quality index. We find that quality is clustered in fairly homogenous neighborhoods, as expected when households' marginal willingness to pay for quality is affected by neighboring amenities. To test the third implication, we exploit the exogenous change of the built environment during the GDR period. In particular, taking pre-1949 as the before and post-reunification as the after period, we use the difference-in-differences methodology to examine the reduced form effect of the quality of neighboring buildings on the quality of newly-built ones. Our estimates show that the quality of new buildings in the east half of the city is significantly lower than one would expect in the absence of any low quality additions to the housing stock during Berlin's division. Conditional on the fraction of buildings added to east neighborhoods between 1949-1989, the reduced quality translates into a loss of building value of about 6 to 17 percent relative to a new building in Berlin's untreated west half. This result remains robust if non treated neighborhoods, i.e. neighborhoods with little post-1949 additions to the housing stock, are used as an additional control group.

The remainder of the paper is organized as follows. Section 2 gives an overview of Berlin's suburban development history and motivates why Berlin's division led to an exogenous treatment of the housing stock. Section 3 presents a model of housing investment with endogenous building quality. The model gives three predictions, which we test using data from Berlin's single-family house market. Section 4 presents the data. Section 5 presents the empirical methodology and gives the test results. The final Section 6 concludes. The Appendix provides further details of the analysis.

2 Berlin's suburban history

2.1 Period up to 1945

The development of residential single-family areas began in Berlin in the second half of the 19th century, when industrialization caused rapid economic growth. In 1850, Berlin had a population of 418,733, increasing to 774,498 by 1870, and 1.9 million by 1919. Single-family houses were attractive for wealthy households, who did not want to live in the polluted and crowded city. Early single-family houses were dominantly villas, mostly constructed in villages and small towns surrounding Berlin. In only a few decades, these towns and villages grew to sizeable cities themselves.

Suburban areas were mostly developed by profit-seeking land companies ('Terrain-Gesellschaften'), which raised sufficient capital via share issues to undertake large projects. These companies acquired large sites, mostly former manors ('Rittergüter'), planned the settlement, provided infrastructure (such as sewerage, schools, train stations, subway lines, and steamboat connections) and then subdivided and sold the remaining land. The construction of individual single-family buildings was carried out by independent small firms either on their own account or on behalf of the future house owner (Fisch, 1989).

The managers of land companies were aware that the aesthetic quality of buildings may have an effect on prospective buyers' willingness to pay and thus on the development profits. Exemplary is J.A.W. Carstenn, responsible for the settlements Friedenau, Wilmersdorf, and Lichterfelde in the south of Berlin, whose company not only constructed streets and train stations connecting to Berlin, but in 1881 also convinced Siemens & Halske to run the world's first electric tram in Lichterfelde (Bodenschatz, 2001a). The locations of these settlements were chosen because of their proximity to the summer residences of the Prussian gentry and 'Naturschönheiten' (natural beauty), as Carsteen called it, such as lakes and forests. To ensure the built quality of a development, Carstenn's company, like other land developers, included covenants in the land sales contracts stipulating that the buildings to be constructed had to be of appropriate standard (Braum, 2003, p. 42; Bernhardt, 2008, p. 77). The covenants did not specify the building design, although land companies occasionally suggested specific architects.

In the 1890's, building co-operatives started providing single-family houses for middle class families.[4] The buildings were simpler and more standardized than those in the settlements initiated by profit-maximizing land companies. The importance of building co-operatives for single-family house construction increased substantially after 1920, when greater Berlin was established. The new city brought many surrounding towns and smaller cities under central administration, enlarging Berlin's population to 3.9 million inhabitants. The profit-maximizing land companies adapted to the changing market by shifting their focus from land development to building construction. Large projects were often conducted jointly with building co-operatives and with financial support from the government. Such projects were often designed by modernist architects and consisted of multi-dwelling tenement buildings and single-family houses ('Hufeisensiedlung' in Neukölln, 1925-1927, 'Onkel-Tom-Siedlung' in Zehlendorf, 1926-1932). The design of the buildings was often functional and used building materials such as glass and steel. Semi-detached and row houses became more common (Kuhn, 2001).

After 1933, the year in which the Nazis took power, two further settlements were

[4] At the same time, the most luxurious German villa development took place. Landscaping for the 'Villenkolonie Grunewald' in the southwest of Berlin included the creation of two new lakes and a complete remodeling of the area using the excavated soil (Bodenschatz, 2001b).

developed in Zehlendorf ('Berliner Strasse', 1937-1938, 'SS-Kameradschaftssiedlung Krumme Lanke', 1938-1940). The latter development was for SS personnel and buildings had a folkloristic design. Community buildings were planned, following the national-socialist ideology, but were not realized (Braum, 2003). Individual construction of single-family houses by profit-maximizing developers remained very important too, and took place in proximity to the early villa developments, (Bernhardt, 2008, pp. 80) and Häußermann and Kapphan (2002, p. 88). Single-family house construction stopped with the outbreak of the war in 1939; Berlin's population peaked at 4.5 million in 1942.

2.2 Period between 1945-1989

After the war, Germany was divided into four occupied zones, each controlled by one of the four allies (United States of America, the United Kingdom, France, and the Soviet Union). Berlin, located completely in the Soviet zone, had special status and was itself divided into four zones. In 1949, the GDR was founded in the Soviet zone. Berlin's east half, the city's Soviet zone, became the capital of the new centrally-planned socialistic state. In he same year, the FGR was founded in the remaining three occupied zones. Berlin's west half became a federal state of the new market-based democratic state. In 1950, 2.1 million people lived in the west half and 1.2 million in the east half.

In Berlin's west half, construction of single-family houses stayed in the hands of profit-maximizing developers. The construction industry consisted of many small and highly competitive firms. Most construction took place in the traditional single-family house districts Zehlendorf, Wilmersdorf, and Steglitz. Buyers often came from the central Kurfürstendamm area, which attracted high-rent paying lawyers, architects, and medical doctors (Häußermann and Kapphan, 2002, pp. 77). Most single-family houses were individual projects, designed by independent architects. Only a few developments combined single- and multi-family buildings, such as the 'Garden City Düppel' in Zehlendorf (1983-1986) (Braum, 2003). Large multi-dwelling developments were constructed too, first in central inner-city locations and later at the outskirts of the Berlin's west half. Particular in the first decades of the period, traditional pre-war buildings were less valued by the modernists zeitgeist, which led to dilapidation and occasionally to the demolition of such buildings. Infrastructure projects, such as new and wide roads, utilities, and multi-family dwellings, changed the appearance of many existing neighborhoods. However, beginning in the seventies, neighborhood preservation societies lobbied for a more careful treatment of the old settlements (Bodenschatz, 2001b, pp. 141, for Grunewald; Bodenschatz, 2001a, pp. 119, for Lichterfelde). At the end of the period, careful restoration and modernization made these buildings highly attractive again.

In the GDR, the construction industry was nationalized into a few state-owned regional industrial conglomerates ('Wohnungsbaukombinate', initially 21, later 15), which produced standardized parts, constructed buildings, and were also responsible for the interior fitting. Berlin's east half, the capital of the GDR, had its own conglomerate. Many private tradesmen and their firms had to merge with the industrial conglomerates. Industrial building construction required different skills than the construction of traditional single-family houses. This implied that the knowledge on the upkeep of the existing buildings, which was engrained in the defunct traditional firms, disappeared over time. Self-employed independent architects faced an even tougher fate; they had to work in hierarchical organized state-owned firms, thereby losing their creative independence (Topfstedt, 1999, pp. 434).

Economic constraints led the GDR to focus on mass-produced large tower blocks. The construction of these blocks exploited economies of scale of standardization ('Typisierung') and the prefabricated parts, especially concrete slabs ('Plattenbau'). It also implied that the constructed buildings had a very homogeneous appearance. Huge settlements of such blocks were concentrated in a few locations in Berlin's east half. For instance, 65,000 new flats were constructed in towers with 11 floors between 1976 and 1989 in Berlin Marzahn. The flats were small and the quality poor (Strubelt et al., 1996, pp. 36). In 1991, 166,000 people lived in these buildings (Häußermann and Kapphan, 2002, pp. 164).

With the focus on multi-dwelling construction, single-family house construction contributed only 10 percent of the overall volume. The housing development programme, which was enacted at the VIII. Parteitag der SED 1971, encouraged the construction of such houses to attract skilled workers and families to areas where their skills were needed (Bernhardt and Wolfes, 2005). However, it became obvious that mass-produced concrete slabs were not suitable and too expensive for the construction of individualized single-family houses (Kegler, 2005, p. 212).

Single-family house construction had to rely mostly on self-initiative. Land was allocated by local councils and districts and therefore—at least in principle—available. In most cases, land was allocated on empty parcels in already existing single-family house settlements. Once allocated, the prospective housebuilder obtained the right of land use, but not full ownership (which did not exist in the socialist state). Construction material was generally in short supply in the GDR, and in particular so for the non-prioritized single-family house construction. Builders had therefore to use what they could get.[5] This included finding suitable building material, transportation (a car was often a necessity), and the will and the experience to go through with the project.[6] This implied that only tradesmen and technical proficient workers were able to built their own home (Kegler, 2005, p. 214). The spread of building material, its poor quality, and the fact that many projects were carried out without sufficient professional oversight led to new buildings that were neither in line with natural amenities nor the existing building stock (Kegler, 2005, p. 223).

[5]See Joachim Nawrocki: *Bau selber, Genosse. Wie in der DDR der Bau von privaten Eigenheimen forciert und animiert wird*, published in the West-German weekly *Die Zeit*, No. 13, March 31st 1972, p. 27.

[6]Used material was employed when suitable, such as railway tracks instead of T-beams (Pauli, 2005, p. 37).

The socialistic centrally planned system led therefore to a leveling of building qualities between neighborhoods. Moreover, the pre-1949 building stock was not maintained and deteriorated. An example is the Haus Lemke, constructed in 1932 in the east half district Alt-Hohenschönhausen by the Bauhaus architect Mies van der Rohe. The interior design and the furniture was also provided by van der Rohe's workshop. The Lemkes left the house in 1945, afterwards the Soviet military used it as garage and storage room. In 1962, the GDR security service (MfS) started using the house, but also did not maintain it.[7]

The socialist society also provided less opportunities for individual differentiation and placed less value on it. The social status effect of houseownership was therefore less pronounced and the economic incentives to distinguish the own house less developed than in the west (Herlyn and Harth, 1996, p. 264). Single-family house inhabitants consisted mainly of two groups. First, members of the political and cultural elite, who obtained possession of existing houses via lease contracts ('Überlassungsvertrag'). The original owners of such houses had mostly left the country out of political and economic reasons. Second, members of a more traditional middle-class, who valued homeownership and chose to acquire a 'right to use' of the land ('Dingliches Nutzungsrecht'). This right was recorded in the land register (Glock et al., 2001, pp. 542).

2.3 Period from 1990

Following the German reunification in 1990, the laws of the FRG became effective in the east part. Special laws were enacted to facilitate restitution of owners that were expropriated during the socialistic regime. It was the guiding principle of this process that rightful owners could log claims by the end of 1992 and should be reinstated after the claims were proven. However, individuals who became homeowners in

[7] The building was restored in 2000-2002. It is now open for visitors and houses exhibitions of modern art, see www.miesvanderrohehaus.de.

the east half during the GDR could be exempt from this principle. It mattered if inhabitants obtained the right of use for the single-family house or not. If they had only a lease contract, then the expropriated rightful owner could claim payment of 50 percent of the market value or repossess the house. If inhabitants had the right of use, they gained full ownership without the need of any additional payment. As Glock et al. (2001, p. 547) write, this implied frequently that the GDR political and cultural elite lost houses they seized for themselves during 1949-1989. Households who constructed a building on land allotted to them by the GDR administration could choose after the reunification to buy the land from the rightful owner at half of the assessed land value or they could request a ground lease instead.

In addition to restitution and clarification of ownership rights, the renovation of the infrastructure and the transport connections with west half started immediately after the reunification. Generous subsidies were provided for houseowners in the east half to renovated their buildings.

We present next our model of building construction in a neighborhood. The quality of natural amenities and of neighboring buildings are positive externalities and land owners might adjust their own investments in reaction to the investment of neighboring land developers. The model of housing investment provides us with predictions that will be tested with our data.

3 Housing investment with endogenous building quality

3.1 Households

A household living in the city spends income y on the composite good $x \in \mathbb{R}_+$ and the quality of the building $q \in \mathbb{R}_+$. The price per unit of x is given and normalized to one, the price for q is p, and the budget constraint is $y = x + p$. Household's preferences are represented by the utility function $u(q, x; a) = x + f(q; a)$. The vector $a \in \{z \colon z \leqslant \overline{a},\ z \in \mathbb{R}^J_+\}$ measures the levels of the J local amenities in the neighborhood, such as the qualities of neighboring buildings and the amount of green space nearby. The function $f(q;a)$ is continuously differentiable and strictly concave in q.[8] We assume further that $f(0;a) = 0$ and that $f(q;a)$ is strictly increasing in each of a's elements if $q > 0$.[9]

The city has many different neighborhoods in which a household could locate. A spatial equilibrium requires that a household's utility level is the same in all neighborhoods. We set this utility level equal to y. Household's willingness to pay function for q becomes $p(q;a) = f(q;a)$. It follows from our assumption on $f(q;a)$ that $p(q;a) \geqslant 0$ with strict inequality for $q > 0$. We can also assume that $p(q;a) \leqslant y$ for all feasible combinations of q and a, because y is a free parameter of the model.[10]

3.2 Landowners

The profit function of the owner of an undeveloped site is

$$\Pi(q;a) = p(q;a) - c(q) \ . \tag{1}$$

Construction cost $c(q)$ is a continuous differentiable convex function without fixed cost, $c(0) = 0$. We assume further that $\nabla_q p(0;a) - \nabla_q c(0) > 0$. It follows from the strict concavity of $p(q;a)$ and the convexity of $c(q)$ that the profit function is strictly concave in q and $\Pi(0;a) = 0$. Profit is also strictly increasing in each of the a_js if $q > 0$.

Optimal quality: The landowner chooses $q^* \in [0, \overline{q}]$ to maximize the profit in Eq. 1. The solution to this problem is the optimal quantity, which is given implicitly

[8]Strict concavity implies $\nabla_q f(q;a) > 0$ and $\nabla_{qq} f(q;a) < 0$, where $\nabla_x f(x)$ denotes the first derivative of $f(x)$ with respect to x, $\nabla_{xx} f(x)$ denotes the second derivative.

[9]In case that a_j is a disamenity, such as noise or pollution, a higher level of a_j indicates less of the 'bad'.

[10]It should be mentioned that any strictly quasi-concave utility function leads to a strictly concave willingness to pay function for q. Using the quasi-linear utility function reduces the complexity of the analysis.

by the first order condition $\nabla_q p(q^*; a) = \nabla_q c(q^*)$.[11] The second order condition holds $\nabla_{qq} p(q^*; a) - \nabla_{qq} c(q^*) < 0$ too. The optimal quality $q^*(a)$ is therefore a function of the amenities a. Total differentiation of the first order condition leads to

$$\nabla_{a_j} q^*(a) = \frac{\nabla_{qa_j} p(q^*)}{-\nabla_{qq} p(q^*; a) + \nabla_{qq} c(q^*)} \ . \tag{2}$$

Result 1: The response of $q^*(a)$ to a change of a_j depends on the sign of the numerator in Eq. 2. Three cases are possible:

(i) The numerator is zero and household's marginal willingness to pay for quality is unaffected by the change of the amenity level. Landowners maximize profits by constructing buildings with homogenous quality.

(ii) The numerator is strictly positive and households have a higher marginal willingness to pay for building quality at higher levels of the amenity. Building quality and the amenity are *complements*. Landowners will maximize profits by constructing buildings with higher quality at better locations.

(iii) The numerator is strictly negative and households have a lower marginal willingness to pay for building quality at higher levels of the amenity. Building quality and the amenity are *substitutes*. Landowners will maximize profits by constructing buildings with lower quality at better locations.

Result 2: Whereas $q^*(a)$ can increase, decrease, or stay constant with an increase in a_j, the profit will increase always,

$$\nabla_{a_j} \Pi(q^*; a) > 0 \ . \tag{3}$$

This follows from Eq. 1 with the envelope theorem.

We next examine the interaction of landowners in a neighborhood with $S \geqslant 2$ sites. Each site s is owned by a different owner and sites are developed simultaneously. We split the vector of amenities for site s, a_s, into the two vectors q_{-s} and e.

[11] We assume that $\overline{q}$ does not bind and q^* is interior.

The $(S-1)$ vector q_{-s} contains the qualities of all buildings except q_s. With a slight abuse of notation, we let q denote the vector of building qualities in the neighborhood, where $q \in [0, \overline{q}]^S$. The building quality q is an *endogenous* externality, because the S developers choose the profit maximizing quality for their site s in reaction to each other. e measures the level of *exogenous* amenities in the neighborhood and $e \in \{z\colon 0 \leqslant z \leqslant \overline{e},\ e \in \mathbb{R}_+^{J-S+1}\}$.

Taking q_{-s} as given, the quality $q_s^*(q_{-s}, e)$ maximizes the profit of landowner s from development. We write compactly $g_s(q,e) = q_s^*(q_{-s}, e)$. Note that $\nabla_{q_s} g_s(q,e) = 0$. We collect the S individual quality functions $g_s(q,e)$ in the vector valued function $g(q,e)$. We also write $\Pi(q,e)$ for the $(S \times 1)$ vector of profits.[12]

Result 3: A Nash equilibrium fulfils

$$q^n = g(q^n, e)\ . \tag{4}$$

In such an equilibrium, no landowner wants to change the chosen building quality given the building qualities chosen by other landowners. Given that $[0, \overline{q}]^S$ is a nonempty, compact, and convex set and that $g(q,e)$ is a continuous mapping of the set into itself, it follows from Brouwer's fixed point theorem that q^n exists.

We next conduct comparative statics by focussing on a stable equilibrium. Stability requires that

$$\dot{q} = B(q - q^n) \tag{5}$$

converges to zero, where $B \equiv \nabla_q g(q^n, e) - I$.[13] This requires that all eigenvalues of B have negative real parts (Murata, 1977, Chap. 3, Theorem 8). Assuming

$$1 - \sum_{i=1, i\neq s}^{S} |b_{is}| > 0 \quad \text{for} \quad s = 1, \ldots, S \tag{7}$$

[12] $\nabla_q \Pi(q,e)$ has zeros on its diagonal and all off-diagonal elements are strictly positive, see Eq. 3.

[13] Row s of the system in Eq. 5 is

$$\dot{q}_s = \left\{ q_s^n + \sum_{i \neq s} \nabla_{q_i} g_s(q^n, e)(q_i - q_i^n) \right\} - q_s\ , \tag{6}$$

where the term in the curly brackets is a first-order approximation of $g_s(q,e)$ around q^n.

is sufficient for the eigenvalue criterion to be fulfilled.[14] The stability assumption in Eq. 7 implies that if landowner s deviates from the Nash equilibrium quality by dq_s^n, then the reaction by all other landowners, $\iota' dq_{-s}^n$, will be smaller in absolute value.

With Eq. 4, an increase of the exogenous amenity j leads to change of the building qualities of

$$dq^n = C^{-1} \nabla_{e_j} g(q^n, e) de_j \ , \tag{8}$$

with $C \equiv -B$. We assume in the ongoing that all off-diagonal elements of C are of the same sign.

Result 4: First, the building quality will not vary between neighborhoods if quality is not affected by exogenous amenities, $\nabla_{e_j} g(q^n, e) = 0$. Second, for the case where building quality is affected by exogenous amenities, we focuss on the case of complements, $\nabla_{e_j} g(q^n, e) > 0$. The result for the case of substitutes, $\nabla_{e_j} g(q^n, e) < 0$, follows similarly. Using Result 1, we can distinguish three cases:

(i) If building qualities are neither complements nor substitutes for each other, we have $C^{-1} = I$ and it follows from Eq. 8 that $dq^n > 0$. Everything else equal, it follows that the building quality should be higher in neighborhoods with a higher level of amenity e_j.

(ii) If building qualities are complements for each other, the off-diagonal elements of C are all negative and the column sums all positive, see Eq. 7. The matrix C^{-1} is then positive and has a strictly positive diagonal. It follows from Eq. 8 that $dq^n > 0$.[15] Everything else equal, the effect of an increase in amenity e_j is enforced by the endogenous feedback effect.[16]

[14] Eq. 7 ensures that B is a Hadamard matrix; because B has also a negative diagonal, the result follows (Murata, 1977, Chap. 1, Theorem 20).

[15] Under these conditions, C is a Minkowski matrix and all principal minors are positive. The Hawkins-Simon theorem provides the non-negativity result, see Murata (1977, Chap. 1: Lemma 1, Chap. 2, Theorem 30).

[16] We have

$$C^{-1} = I + \sum_{i=1}^{\infty} \{\nabla_q g(q^n, e)\}^i \tag{9}$$

(iii) If building qualities are substitutes for each other, C^{-1} is positive quasi-definite, but no general result can be derived.[17] This only changes if we assume either symmetric external effects or if specific functional assumptions are made. In the case of symmetry, location in the neighborhood does not matter, and C is symmetric with identical off-diagonal elements and the effect of exogenous amenity j on the building quality, measured as $\nabla_{e_j} g_s(q^N, e)$, is the same for all s. It follows that $dq_s^N > 0$ for all sites, see Appendix A.1. The model of Rossi-Hansberg et al. (2010) is an example for functional assumptions that ensure that the endogenous substitutional reaction is smaller than the initial exogenous effect.

Buildings can be erected instantly and the land values in a neighborhood equal therefore the profits from development. If the exogenous amenity j increases, land values increase by

$$d\Pi = \{\nabla_q \Pi(q^n, e) C^{-1} \nabla_{e_j} g(q^n, e) + \nabla_{e_j} \Pi(q^n, e)\} de_j \ . \tag{10}$$

The gradients of the neighborhood profit function are both strictly positive.

Result 5: Observe first that $d\Pi > 0$ even if external amenities have no effect on the building quality and $\nabla_q g(q^n, e) = 0$. This implies that land has a higher value in neighborhoods with nicer external amenities. The quality of buildings, however, is the same in different neighborhoods. This effect on the land values will be enforced if cases (i) and (ii) of Result 4 apply. In both cases, $C^{-1}\nabla_{e_j} g(q^n, e)$ is strictly positive and land values increase with exogenous amenities. In case (iii) of Result 4, however, it depends on further assumptions about the magnitude of the substitution between building qualities whether $d\Pi$ is positive or not.

The model can be extended easily to treat exogenous building construction. In particular, if some landowners have no access to the appropriate construction

for the nonnegative square matrix $\nabla_q g(q^n, e)$ Murata (1977, Chap. 4, Theorem 11)

[17] C has a positive dominant diagonal and is therefore positive quasi-definite. Its inverse is then positive quasi-definite too, see Murata (1977, Chap. 2, Theorem 37).

materials and techniques, then the quality of their building will be different from the profit-maximizing quality q^*. Assume that the previously ignored landowner $S+1$ is of this type. The quality of the building is q_{S+1}. The other S landowners behave as before. In this case, the S elements of $\nabla_{q_{S+1}} g(q^n, e)$ have the same sign as the endogenous feedback effects.

Result 6: If there is no endogenous feedback effect, a change of the exogenous q_{S+1} has no effect on the quality of other buildings in the neighborhood. It has, however, an effect on land values in the neighborhood, because land values increase with the level of exogenous amenities, $d\Pi = \nabla_{q_{S+1}} \Pi(q^n, e) > 0$, see Result 5. If endogenous building qualities are complements, then a higher exogenous q_{S+1} increases land values and the level of the endogenous building qualities. If endogenous building qualities are substitutes, then the net effect on land values and the endogenous building quality is ambiguous. If the endogenous reaction does not fully crowd out the initial effect of a change in q_{S+1}, then a higher exogenous q_{S+1} decreases the quality of other buildings in the neighborhood, see Result 4.

The theoretical analysis shows that positive externalities alone are not sufficient to motivate variation of the building quality between neighborhoods. Nicer locations with higher exogenous amenities imply higher profit opportunities for landowners and therefore higher land values, but this does not necessarily imply higher quality buildings too. A positive correlation between exogenous amenities and building qualities requires that both are complements. If building qualities in a neighborhood react to each other, then such a correlation will be enforced further if qualities are complements. No general result could be derived for the case where endogenous qualities are substitutes.

The model provides us with three testable implications. First, if the level of exogenous amenities is a positive externality, we expect that land values are positively related to these amenities, see Result 5. In case that endogenous building qualities are substitutes, this requires that the feedback effect is not too strong. The first step of our empirical analysis is therefore to analyze if given exogenous amenities have a positive effect on the value of undeveloped land. Second, if exogenous amenities affect households' marginal willingness to pay for quality, buildings will be clustered by quality, see Result 4. In the second step, we therefore examine if buildings are clustered between neighborhoods. Third, if the quality of buildings is endogenous, the impact of given natural amenities will be enforced (weakened) further if the quality of neighboring buildings are complements (substitutes). We use the setting of the natural experiment to examine if an exogenous decrease of the average building quality in a neighborhood affects the quality of newly-built houses.

4 Data and construction of quality index

The main data for our empirical analysis comes from Berlin's Committee of Valuation Experts (GAA, Gutachterausschuss für Grundstückswerte) out of its transaction database.[18] The data covers 1996-2008 and provides information on all arms-length transactions of single-family houses and undeveloped residential land in Berlin. Information includes the transaction price, the geographic location, and building characteristics if the site is developed and therefore a house. We use this data in several stages of our analysis. In particular, we use the data to compute a normalized measure of building quality for each transacted house.

We also use data from other sources in the analysis. Berlin's Statistical Office provides information on Berlin's area and population through history (Statistisches Landesamt Berlin, 2001). Neighborhoods can be delineated according to the 23 administrative districts of 1990 and the 195 statistical areas defined by the Statistical Office, respectively.[19] The Statistical Office also provides information from the cen-

[18]The GAA is entitled by law to request and collect information on real estate transactions occurring in Berlin. The GAA uses this information to conduct valuations needed for administrative and official purposes (public court, legal portioning, compulsory purchase) and to provide information about the real estate market to professionals and the interested public.

[19]The statistical areas reflect more closely the city's neighborhoods than the substantially larger

sus on the housing stock at the level of statistical areas (Statistisches Landesamt Berlin, 1991, 1997), and publishes the Berlin consumer price index (CPI) in its Statistical Report M I 2. We use the CPI to convert nominal figures into real year 2000 Euros. Digital maps and further geo-coded information is provided by Berlin's Senate Department for Urban Development. This information includes the location of lakes, district and statistical area boundaries, and an expert-based rating of the overall amenity quality of an area.[20]

[Figure 1 about here.]

4.1 Description of single-family house transactions

We observe 18,961 single-family house transactions, which show a wide variation of building vintages. Figure 2 shows a histogram of the year of construction for the buildings of the observed houses. 7,841 buildings were constructed before 1949, 6,745 during the division period 1949-1989, and 4,374 since the reunification in 1990 and until 2008.

[Figure 2 about here.]

At the level of statistical areas, the transacted houses closely resemble the age distribution of the housing stock in the year of reunification.[21] This indicates that the transacted houses are fairly representative with respect to the current age distribution of Berlin's single-family housing stock.

The locations of the transacted houses are shown in the map of Berlin in Figure 1. Section 2 explained that the locations of many suburban neighborhoods were

districts. Some of the data used, however, is only available on the district level.

[20]The rating indicates the level of natural amenities, the quality of existing buildings, and access to public transport and shopping facilities within the neighborhood.

[21]Figures are not reported here.

established by the end of the pre-1949 period. Figure 1 shows a fair mixture of building vintages in most neighborhoods, so that the initially developed areas continue to be attractive for new construction. Zoning regulations, which were enacted in the FRG in 1960, may also contribute to the local clustering. The observed proximity of buildings of different vintages is required to test the predictions of our model.

Table 1 reports summary statistics for the single-family house transactions by period of construction and by half of the city. The land value of a transacted house is predicted with a semiparametric regression using transaction prices of undeveloped residential land. The building value is the transaction price net of the notional land value. The mean building value of houses located in the west half is always higher than the building value of houses in the east half in each of the three periods. The mean building values are affected by physical depreciation and building characteristics. The last variable 'quality index' in the first panel of Table 1 controls for such effects. The index ranks the (unobserved) quality of buildings on the unit interval, where a value of 0.5 represents a median quality. The computation of the land value and the quality index is explained in Subsection 4.3.

[Table 1 about here.]

According to the average quality index, the quality of buildings in the west half was non-decreasing over the three periods, whereas it fell during the GDR period in the east half. It is now still lower in the east half than it was before the division of the city.

4.2 Description of residential land transactions

We observe 20,754 undeveloped residential sites.[22] Table 2 presents summary statistics. The standard deviation of the price variable reveals that there is substantial

[22]The initial data set includes transactions of all land sites in Berlin. Information on zoning regulations and existing structures in the neighborhood of a site allow us to exclude non-residential sites from the sample.

variation in observed land prices. Most of the sites are located in suburban neighborhoods as indicated by the mean distance to Berlin's central business districts (CBD).[23] According to the expert-based rating of the amenity quality, almost half of the sites are located in neighborhoods with medium quality. A sizeable amount of sites are located in low and high quality neighborhoods, respectively. The lower three panels of Table 2 summarize further characteristics of the site, as well as of the transaction process. These variables will serve as controls in our empirical applications.

[Table 2 about here.]

4.3 Construction of quality index

We employ the hedonic model proposed by Bajari and Benkard (2005) to compute the quality of a building.[24] The resulting quality index is based on the notion that market participants' willingness to pay for otherwise identical buildings will increase with their inherent quality. The distribution of building values, i.e. the house price net of the value of the underlying land, therefore allows us to rank buildings with respect to their unobserved quality.

Specifically, let p_i^H denote the transaction price of house i and let v_i^L represent the value of the underlying land.[25] The house price is the sum of the value of the location and the building structure. The building value is thus defined as

$$v_i^B \equiv p_i^H - v_i^L \ . \tag{11}$$

[23]We consider two separate CBDs: for land in the the west (Breitscheidplatz, close to the Kurfürstendamm) and the east (Alexanderplatz, close to the historical centre).

[24]Bajari and Benkard (2005) extend the Rosen-Lancaster type hedonic model of demand for differentiated products by incorporating a hedonic price function that has a general nonseparable form and allows for unobserved product characteristics. We employ their first stage estimation procedure to infer the unobserved characteristic, i.e. the building quality.

[25]We use no subscript for the period of sale, because we conduct the analysis of building values in real terms.

We collect observable characteristics of the building in the vector x_i and denote its inherent, but unobserved, quality with q_i. The observed characteristics, such as age or state of repair, are assumed to be independent of the unobserved quality.[26] Furthermore, we assume that x_i and q_i are mapped into building values by the following nonparametric function

$$v_i^B = v\left(x_i, q_i\right) \ , \tag{12}$$

where $v(\cdot)$ is assumed to be (i) Lipschitz continuous and (ii) strictly increasing in q_i. Bajari and Benkard (2005, Theorem 2) then show that q_i is identified, up to a monotonic transformation, by

$$F_{v^B|x=x_i}\left(v_i^B\right) = \Pr\left[v(x,q) \leq v_i^B | x = x_i\right] = \Pr\left[q_i \leq v^{-1}(x, v_i^B)\right] = q_i \ , \tag{13}$$

where the second equality holds because of the independence between x_i and q_i, and the last equality holds after normalizing q_i using its distribution function.[27] The quality of a building can thus be represented by the conditional cumulative distribution function (CDF) of building values.

In order to actually obtain the quality index defined by Eq. 13, we proceed as follows. First, we estimate the notional land value for each house in our sample. Let p_{it}^L denote the transaction price of an undeveloped residential site i in period t, and let s_i denote its size in square meter. Let $l_i = (l_{1,i}, l_{2,i}) \in \mathbb{R}^2$ be cartesian coordinates that represent a location in Berlin. We employ the following partial linear model

$$\ln p_{it}^L = z_{it}\beta + m\left(l_i, s_i, t\right) + \varepsilon_{it} \ , \tag{14}$$

where the vector z_{it} collects a set of binary variables that capture unusual features of the land site, as well as unusual circumstances of the transaction process , see Table

[26]Given the nonseparable form of Eq. 12, an independence assumption is not as restrictive as in linear models. This is because nonseparability allows interaction between the unobserved q_i and observed x_i that replicates models of heteroscedasticity.

[27]The normalization implies that the marginal distribution of the quality index, q_i, is uniformly distributed on the unit interval.

2. β is a parameter vector and $m(\cdot)$ is a smooth function that need to be estimated. The random error term ε_{it} is assumed to be mean independent from the explanatory variables. We estimate Eq. 14 using the approach pioneered by Robinson (1988). Details are given in Appendix A.2.

Second, we compute the notional land value of a house with lot size s_0 at location l_0 using

$$v_{0t}^{L} = \exp\left\{ z_{0t}\widehat{\beta} + \widehat{m}\left(l_0, s_0, t\right)\right\} \ , \tag{15}$$

where the time period t is set according to date of the house sale.[28] The corresponding indicators in z_{0t} are set to one if the house has unusual features that relate to the land and in the presence of unusual circumstances during the transaction process. We then compute the building value using the observed transaction price of the subject house and the notional land value, see Eq. 11. Nominal building values are converted into real terms (year 2000 Euros) with the Berlin CPI.

Finally, we estimate the conditional CDF of building values in real terms, see Eq. 13. In particular, we employ the nonparametric kernel estimator proposed in Li and Racine (2008). We include the building's age, floor size, a set of binary indicators for its state of repair, and a set of binary indicators for the type of building in the conditioning set x_i.[29] The inherent quality of each building is thus assumed to be independent from physical depreciation, floor size, and type of building. Further details on the estimation procedure are given in Appendix A.3.

Summary statistics of the estimated quality index are given in the last row of Panel A in Table 1. While the mean quality of buildings constructed before 1949 is roughly the same in both halves of the city, the quality in the east half is lower for,

[28] By taking the antilog of predicted log prices, we obtain an consistent estimate of the median of the land price distribution rather than its mean. An asymptotic unbiased re-transformation of median prices to mean prices requires an estimate of the standard error of the prediction. For computational ease we refrain from this correction.

[29] We distinguish between three state of repairs (bad, average, excellent) and three building types (detached, semi-detached, row house).

both, buildings constructed during the division and after reunification. To formally inspect if these differences are statistically significant, we employ a nonparametric Wilcoxon rank sum test. The test's null hypothesis is that of no difference, so that the quality index is equally distributed in both halves of the city. Table 3 gives results of the test. For buildings constructed before 1949, we can reject the null hypothesis of equally distributed building qualities at the 3.1 percent significance level, see Column (1). Although statistically significant, the point estimate for the probability of a building in the west half of being of better quality than a building in the east half is 51.5% and therefore not very different from 50%, see Column (2) in Table 3.[30] The probability differential between the west and east halves increases for buildings constructed during the division of Berlin, 1949-1989, and buildings constructed since reunification in 1990. In both cases, the test results indicate clearly that building qualities are different. On average, additions made to the housing stock in the east half during the period 1949-1989 were of lower quality than in the west half. Moreover, these low quality additions seem to impact on the quality of current constructions as indicated by the continuing divergence of the quality index in the third period under consideration.

[Table 3 about here.]

5 Testing the implications of the model

In this section, we take the testable implications of the theoretical model presented in Section 3 to the data. First, we examine if natural and built amenities are a positive externality by regressing the price of undeveloped land on an expert-based rating of the overall quality of a neighborhood's amenity level. Second, we examine if building qualities cluster into homogenous neighborhoods as implied by households'

[30] Berlin's most luxurious pre-1949 developments can be mainly found in the southwestern neighborhoods of Dahlem, Grunewald, and Lichterfelde, see Section 2. It is thus not surprising that the quality of pre-1949 buildings in the west half is on average slightly larger than in the east half.

willingness to pay for amenities. We therefore apply tests for spatial autocorrelation in the building quality index. While the tests for these two implications of the model are straightforward and, in principle, applicable to data from any city, it is more challenging to test if the building quality of neighboring houses is complementary or substitutive for the quality of other buildings. This is because a high level of natural amenities alone may attract the development of high-quality buildings. If not all relevant amenities can be observed, the quality of buildings will be correlated because both they are related individually to these amenities.[31] We avoid this problem by exploiting the fact that natural amenities remained fairly unchanged in Berlin since the 1920ties, while the addition of GDR buildings during Berlin's division lowered the average building quality in the east half. This unique set-up provides the exogenous variation needed to identify the effect of neighboring buildings on the quality of newly constructed ones.

5.1 Land prices and neighborhood amenities

The first implication of the model is that land prices should be positively related to the level of natural and built amenities in a given neighborhood if these amenities are a positive externality. To test for the presence of externalities we employ linear regressions of the following form

$$\ln \tilde{p}_{it}^{L} = \alpha_0 + \beta_1 a_{1,it} + \beta_2 a_{2,it} + \gamma x_{it} + \varepsilon_{it} \ , \tag{16}$$

where $\tilde{p}_{it}^{L}$ is the price per square meter of the undeveloped site i in period t. The binary indicators $a_{k,it}$, $k \in (1, 2)$, are set to one if the site is located in a street

[31]Such identification problems arise often in models of social interactions, where observed group behavior could be the result of correlation between individuals' (un)observed characteristics and not the result of their interaction (Manski, 1993, 2000). See Carion-Flores and Irwin (2010), Irwin and Bockstael (2002, 2004), and Noonan and Krupka (2011) for studies on the identification of neighboring amenity effects—land use and landmark buildings—on house prices.

block with an overall low and high level of neighborhood amenities, respectively.[32] Amenity levels are assigned to each site according to the amenity rating provided by Berlin's Senate Department for Urban Development, see Section 4. The reference rating is a neighborhood with a medium amenity level. Additional control variables are collected in the vector x_{it}. In our most extensive specification these controls include the distance to the CBDs, binary indicators for unusual features of the site, as well as unusual circumstances of the transaction. All specifications include a full set of district dummies and time dummies for the quarter of sale.

We fit Eq. 16 to the transaction data on undeveloped residential land by ordinary least squares. We expect a price discount for sites located in neighborhoods with a low level of amenities, $\beta_1 < 0$, and a price premium for sites located in neighborhoods with a high level of amenities, $\beta_2 > 0$.[33]

Table 4 reports the estimation results. Standard errors are corrected for intra-district correlation to account for spatial correlation of the error terms. We present estimates for two specifications of Eq. 16. In Specification 1, only our key explanatory variables, $a_{1,it}$ and $a_{2,it}$, and a set of time and district dummies are included. In Specification 2, additional control variables are added. In both specifications, the estimated coefficients on the neighborhood amenity indicators, $\widehat{\beta}_1$ and $\widehat{\beta}_2$, have the expected signs and are statistically significant ($\widehat{\beta}_2$ in Specification 2 only at the 10 percent level). Relative to residential land in a neighborhood with an average level of given amenities, sites in neighborhoods with a low level of amenities sell with a rebate of about 9 to 10 percent. Residential land in neighborhoods with a high level of amenities, on the other hand, demand a price premium of about 8 to 10 percent.

[Table 4 about here.]

[32] Even though the amenity rating is reported separately for each street block, there is little variation within neighborhoods as defined by statistical areas.

[33] Eq. 16 tests for presence of externalities that stem from any neighborhood amenity. The estimates will thus reveal the effect of the overall level of neighborhood amenities on land values.

The estimated coefficients on the control variables in Specification 2 have reasonable signs. Notably, the coefficient on the indicator variable if the site has direct access to a lake or river ('Lake side') is positive and statistically significant.[34] The presence of this particular amenity increases the price of land by about 33 percent. This large effect can be attributed to the fact that sites with lake access are likely to have high levels of other amenities too. The estimated coefficient thus picks up the direct effect of lake access and positively correlated amenities. Overall, Table 4 provides evidence that the neighborhood and site-specific amenities acts as positive externalities.

5.2 Spatial clustering of building quality

The second implication of the model is that buildings will be spatially clustered by quality if amenities affect households marginal willingness to pay for a building's quality. To test for such quality clustering we employ Moran's test for spatial autocorrelation (Anselin, 1988, Ch. 8). The test is based on the following regression

$$\bar{q}_i = \lambda w_i \bar{q} + \varepsilon_i \ , \tag{17}$$

where $\bar{q}_i$ denotes the demeaned quality index of building i, and $\bar{q}$ is a column vector that contains the demeaned quality index of *all* observed buildings (including observation i). w_i is the i-th row of a symmetric inverse-distance weight matrix with typical element $w_{ij} = 1/d(i,j)$. $d(i,j)$ denotes the Euclidean distance between observations i and j. All elements w_{ij} with $i = j$ are set to zero. Furthermore, the weights for observations outside a threshold radius ($r = 1000m$) are set to zero as well.[35] The unknown parameter λ measures the degree of spatial autocorrelation. Here, a value of -1 indicates perfect dispersion and a value of $+1$ perfect clustering

[34] A site's distance to its CBD, on the other hand, has a significant negative impact on the price of land. This finding is in line with a negative rent gradient as implied by the classic Alonso-Muth model of urban land use.

[35] We have also tried cut-off points of 500m, 2000m, and 3000m. These different neighborhood sizes did not qualitatively change the results presented in Table 5.

of building qualities. ε_i is a random error term assumed to be normally distributed with mean zero and constant variance.

We fit Eq. 17 separately for the west and the east halves of Berlin by least squares to the quality index data. For each half of the city, we run regressions using all observed buildings regardless of the construction period, as well as separate regressions for each of the three periods. For each regression, we calculate z-statistics for the null hypothesis that $\lambda = 0$ according to the formulas in Anselin (1988, p 102). The null implies no spatial autocorrelation.

[Table 5 about here.]

Estimation results for the west half are reported in Panel A of Table 5. The estimated spatial autocorrelation coefficient, $\widehat{\lambda}$, is positive and statistically significant for all four estimates. This implies that single-family buildings in the west half are spatially clustered by quality. The degree of spatial autocorrelation is greatest for buildings constructed before 1949 and since reunification in 1990, respectively. Estimation results for the east half are reported in Panel B. As for the west half sub-samples, we find a positive and statistical significant spatial autocorrelation coefficient for all four estimates. The point estimate of the spatial correlation coefficient is smallest for buildings constructed between 1949-1989 in the GDR. It also has the smallest z-statistic. Thus, providing further evidence that housing investments during the GDR were mainly driven by exogenous factors. Table 5 provides evidence for the clustering of the quality of single-family buildings in Berlin. Buildings are therefore homogeneous in and heterogenous between neighborhoods. This result is consistent with households whose marginal willingness to pay for building quality is affected by neighborhood amenities.

5.3 Building quality and quality of surrounding buildings

The third implication of the model is that the impact of given amenities on the quality of newly-constructed buildings will be enforced if the quality of neighboring buildings are complements for each other. We use a difference-in-differences methodology to test for the presence of a complementary feedback effect.[36] The baseline estimation equation is the following

$$q_{ig,t} \quad = \quad \beta_{0g} + \beta_1 D_t^{After} + \beta_2 D_g^{East} \times D_t^{After} + \varepsilon_{ig,t} \ , \tag{18}$$

where the dependent variable is the quality of building i that has been constructed either before 1949 ($t =$ before) or after 1989 ($t =$ after). The subscript g indicates the neighborhood in which a house is located. We delineate neighborhoods according to the statistical areas as shown in Figure 1. D_t^{After} is a binary indicator that is set to one if a building has been constructed after 1989. This time dummy variable and the neighborhood-specific intercept β_{0g} control, respectively, for shifts in city-wide building quality over time and persistent differences between neighborhoods.[37] D_g^{East} is a binary indicator that is set to one if the building's neighborhood is in the east half of Berlin. The coefficient of interest is β_2, which measures the quality gain of newly-constructed houses in the east half relative to houses constructed before 1949, relative to the same quality gain for houses located in the west half.

The key identifying assumption in Eq. 18, and also the following model specifications, is that the error term is uncorrelated with both the time period t and neighborhood g. Therefore, we assume $E[\varepsilon_{ig,t}|g,t] = 0$. This implies that the coefficient β_2 would be zero in the absence of a leveled quality standard in eastern neighborhoods caused by the buildings constructed during 1949–1989. In this case, ordinary least squares identifies the sign of the endogenous feedback effect of given

[36] Strictly speaking, and in line with the theoretical model, we cannot distinguish between a complementary and a substitutive feedback effect when the later has an endogenous effect that is stronger than the initial effect. We presume that the is an unlikely setting.

[37] The observed building quality may increases over time due to changes in building technology.

built environment on newly-constructed buildings. Given our prior of a complementary feedback effect, we expect that $\beta_2 < 0$.

A drawback of Eq. 18 is that the binary treatment indicator measures the low quality additions to the housing stock in the east half rather crudely. We therefore also conduct a refined analysis that exploits the variation of treatment intensities across neighborhoods in the east half. In particular, let FH_g denote the fraction of the housing stock (as in 1990) in neighborhood g that has been constructed during 1949–1989. We obtain this variable from census data provided by Berlin's Statistical Office. Interacting this variable with the binary treatment indicator in Eq. 18 yields the following estimation equation

$$q_{ig,t} \quad = \quad \beta_{0g} + \beta_1 D_t^{After} + \beta_2 D_g^{East} \times D_t^{After} \times FH_g + \varepsilon_{ig,t} \; . \tag{19}$$

The coefficient β_2 now measures the quality gain of newly-constructed houses in the east half dependent on the concentration of low-quality addition to the respective neighborhood, relative to the quality gain in the west half. We expect again that $\beta_2 < 0$.

To further verify the robustness of the estimates obtained from Eqs. 18 and 19, we exploit that in some neighborhoods in the east half no significant additions to the housing stock were made during the period 1949-1989. Utilizing these untreated neighborhoods as an additional control group will lead to a version of Eq. 18 with a second-order interaction as the key explanatory variable (Meyer, 1995, 4.3).[38] The approach thus allows us to control for two kinds of potentially confounding trends. First, systematic differences in quality changes across neighborhoods in, both, the west and east halves with a high fraction of buildings constructed during 1949-1989. Second, lasting changes in the entire east half of Berlin that are not related to the built environment but may affect the quality of newly constructed buildings.

We specifically define neighborhoods as untreated when the housing stock in the year 1990 is made up of less than one third of buildings that have been constructed

[38] This methodology is also known as the difference-in-difference-in-differences estimator.

between 1949–1989.[39] Let D_g^{FH} be a binary indicator that takes the value one if a building is located in a treated neighborhood. The estimation equation is then given by

$$\begin{aligned} q_{ig,t} &= \beta_{0g} + \beta_1 D_t^{After} + \beta_2 D_g^{East} \times D_t^{After} \\ &\quad + \delta_1 D_g^{FH} + \delta_2 D_g^{FH} \times D_t^{After} + \delta_3 D_g^{FH} \times D_g^{East} \\ &\quad + \delta_4 D_t^{FH} \times D_g^{East} \times D_t^{After} + \varepsilon_{ig,t} \ , \end{aligned} \tag{20}$$

where all variables are defined as before. The coefficient of interest is δ_4 and measures the quality gain of newly-constructed buildings in eastern neighborhoods with a high fraction of buildings constructed during 1949-1989, relative to same the quality gain in western neighborhoods with a high fraction of buildings constructed during 1949-1989, *and* relative to eastern neighborhoods with a low fraction of buildings constructed during 1949-1989. Given our prior of a complementary feedback effect, we expect that $\delta_4 < 0$.

[Table 6 about here.]

Table 6 presents ordinary least squares estimates of Eqs. 18 to 20. The reported standard errors are corrected for intra-neighborhood correlation. We estimate each of the three regressions with two specifications. The first specification includes only the baseline variables as discussed above. The second specification adds additional control variables to adjust for observable differences between neighborhoods in both periods. These include the distance to Berlin's CBDs, an indicator for buildings located at a lake, and the district-level share of votes for the Social Democratic Party in the federal elections of 1928 and 1994, respectively. All specifications include a full set of neighborhood dummies.

In what follows, we will concentrate on our baseline specifications. This is because the inclusion of the additional control variables does not considerably affect

[39] Given the amount of destructed residential buildings during WWII, it is impossible to define control neighborhoods with zero or near zero post-1949 buildings.

the coefficient estimates of interest, neither qualitatively nor quantitatively.[40]

Columns (1) and (3) of Table 6 report estimates of Eqs. 18 and 19. As expected the estimated effect of the GDR treatment is negative and statistically significant. The magnitude of the estimated coefficient $\widehat{\beta}_2$ in column (1) implies that the quality of a newly-constructed house in the east half of Berlin is on average 16.1 index points lower than one would expect in the absence of low quality additions to the housing stock during 1949–1989. Compared to a newly-constructed house with median quality in the west half this decrease in the quality index translates into a building value loss of about 23,300 Euros; a relative loss of about 14.9 percent.[41] In column (3), this figure ranges from 9,900 to 26,000 Euros (a relative loss of 6.4 to 16.7 percent) for neighborhoods with a fraction of 18.7 and 48.6 percent of GDR buildings, respectively.[42]

Column (5) of Table 6 reports estimates of Eq. 19. The estimated coefficient of interest, $\widehat{\delta}_4$, is negative and statistically significant at the 5 percent level. As expected, the point estimate of $\widehat{\delta}_4$ is slightly larger than the estimates in Column (1). Its magnitude implies a quality decrease of 18.5 index points in eastern neighborhoods with a large fraction of buildings constructed during 1949–1989 compared to similarly treated neighborhoods in the west half and untreated neighborhoods in the east half. This decrease in the quality index translates into a building value loss of about 25,300 Euros; a loss of 16.3 percent relative to the median quality house. The relatively large standard error of the point estimate is mainly attributable to the inclusion of additional control neighborhoods, which leaves less independent variation for identification of the treatment effect. Thus, even after controlling for

[40]The estimated coefficients on the control variables have reasonable signs and are statistically significant in most cases.

[41]This figure is calculated as $1 - \left(\widehat{F}^{-1}_{v^B|q=0.5-c,x=x^0}(v_i^B)/\widehat{F}^{-1}_{v^B|q=0.5,x=x^0}(v_i^B)\right)$ where c is the estimated coefficient value of the treatment effect ($\widehat{\beta}_2$ or $\widehat{\delta}_3$). The conditioning set x^0 collects the median characteristics of a single-family house constructed since 1990; the age is set to zero. $\widehat{F}^{-1}$ is computed from the nonparametric cdf estimate described in Appendix A.3.

[42]The range corresponds to the 5 and 95 percent percentile of the FH_g distribution.

unobserved neighborhood changes in the the east half that are not related to the built environment, we find evidence for a complementary feedback effect.

6 Conclusion

From a theoretical perspective, the quality of natural amenities and existing buildings in a neighborhood are a positive externality, generating benefits for its residents. The variation of these amenities throughout an urban area can thus explain geographic variation in land values. If natural amenities and building qualities are complements for each other, such externalities can further motivate the variation of building qualities between neighborhoods that is typical for most cities. Both impacts of neighborhood amenities will be enforced by an endogenous feedback effect when housing investments between neighbors are complements as well.

In this paper we presented evidence for the presence of such an endogenous feedback effect. Berlin's unique recent history provides the exogenous source of variation in building qualities that is needed to disentangle the natural amenity effect and the complementary feedback effect. Our estimates show that the quality of newly-built houses in the east half of Berlin is significantly lower than one would expect in the absence of the low-quality additions to the housing stock that were made during the division of the city. Relative to a newly-constructed building of median quality in the untreated west half this quality decrease leads, on average, to a building value loss of 23,300 Euro. Evidently, the magnitude of the building value loss depends on the particular treatment of neighborhoods in the east half of Berlin during the socialistic period. That said, our evidence points to a economically significant feedback effect of housing investments.

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A Appendix

A.1 Symmetric equilibrium

In the case of symmetric endogenous effects, $b_{is} = b$ for $i, s = 1, \ldots, S$ with $i \neq s$. The $(S \times S)$ matrix C has then ones on its diagonal and $-b$ elsewhere. The matrix C^{-1} has $\{1 - (S-2)b\}u^{-1}$ on its diagonal and bu^{-1} elsewhere, where $u \equiv \{1 - (S - 2)b - (S-1)b^2\}$. Symmetry implies that an increase in the exogenous externality j affects all sites equally. The quality adjustment is

$$dq^n = C^{-1}\iota\nabla_{e_j} g(q^n, e) \ , \tag{A1}$$

which implies

$$dq_s^n = \left(\frac{1+b}{u}\right)\nabla_{e_j} g(q^n, e) \tag{A2}$$

for $s = 1, \ldots, S$. The first term on the right-hand side is the multiplier. If $b = 0$, one building's quality is neither substitute nor complement for the quality of other buildings and the multiplier becomes one. The building quality in a neighborhood will increase with an increase of the exogenous amenity, but the initial effect will neither be enforced nor weakened by endogenous quality adjustments. If the qualities are complements, then $0 < b < (S-1)^{-1}$, where the second inequality follows from Eq. 7. In this case, the multiplier is strictly positive. To see this, observe first that u increases if $b > 0$ becomes smaller; observe second that if b were $(S-1)^{-1}$, then $u = 0$. This implies $u > 0$. Observing further that $1 + b > 0$, the multiplier is therefore strictly positive. Moreover, it is easy to check that the multiplier is larger than one. In the case of complements, the effect of a change in an exogenous amenity is therefore enforced. If qualities are substitutes, $-(S-1)^{-1} < b < 0$, where the first inequality follows from Eq. 7. It follows from these inequalities that both $1 + b > 0$ and $u > 0$, so that the multiplier in Eq. A2 is strictly positive. However, it is easy to check that the multiplier is smaller than one. Some of the initial effect on building qualities is crowded-out by the endogenous substitutive effect. Symmetry ensures, however, that the net effect is still positive.

A.2 Semiparametric land price regression

Estimation algorithm

To estimate the partial linear model given by Eq. 14 we proceed as follows. First, nonparametric kernel estimates of

$$\widehat{E[\ln p_{it}^L | l_i, s_i, t]} \quad \text{and, respectively,} \quad \widehat{E[z_{it} | l_i, s_i, t]} \tag{A3}$$

are constructed. We specifically employ the Nadaraya-Watson kernel estimator (Härdle et al., 2004, Ch. 4). The weights that are assigned to each observation are derived from a Gaussian product kernel function and put more weight on observations which are closer to observation i. The corresponding bandwidths are selected by the cross-validation algorithm explained in Appendix A.4. Second, the parametric regression

$$\ln p_{it}^L - \widehat{E[\ln p_{it}^L | l_i, s_i, t]} = \left[z_{it} - \widehat{E[z_{it} | l_i, s_i, t]} \right] \beta + \nu_i \tag{A4}$$

is fitted via ordinary least squares. Robinson (1988) shows that the estimates of β that are obtained by this method are $\sqrt{n}$-consistent. Third, the nonparametric regression

$$\ln p_{it}^{L} - z_{it}\widehat{\beta} = m(l_{it}, s_i, t) + \epsilon_{it} \tag{A5}$$

is fitted via the Nadaraya-Watson kernel estimator. Again the bandwidths are selected by the cross-validation algorithm explained below. This regression leads to an consistent estimate of the nonparametric part of Eq. 14. Finally, we predict the (log) notional land value for a house at location l_0 with lot size s_0 that is sold at time t by

$$\ln v_{0t}^{L} = z_{0t}\widehat{\beta} + \widehat{m}(l_0, s_0, t) \ . \tag{A6}$$

Estimates of the parametric effects

We fit Eq. 14, to the data on undeveloped residential land, see Table 2. The vector z_{it} includes binary indicator variables for unusual features of the lot, unusual business circumstances, and the level of recoupment charge for public infrastructure. Table A1 presents estimates of the parametric effects. The estimated coefficients are statistically significant. The signs of the point estimates, as well as the magnitude are reasonable. Moreover, the overall fit of the model, as measured by the R^2, is remarkably well.

[Table A1 about here.]

A.3 Nonparametric estimation of conditional cdf

In order to estimate Eq. 13 for a building with building value v_0^B and structural characteristics x_0, we employ the kernel estimator suggested in Li and Racine (2008):

$$\widehat{F}_{v^B|x=x_0}\left(v_0^B\right) = \frac{N^{-1}\sum_{i=1}^{N} G(v_0^B - v_i^B)\mathcal{K}_\gamma(x_i, x_0)}{N^{-1}\sum_{i=1}^{N} \mathcal{K}_\gamma(x_i, x_0)} \ , \tag{A7}$$

where N is the total number of observations. $G(v)$ is the distribution function derived from a univariate kernel function for a continuous variable:

$$G(v) = \int_{-\infty}^{v} \mathcal{K}_{h_0}(u)du \ , \tag{A8}$$

with h_0 being the bandwidth associated with v_i^B and $\mathcal{K}_h(\bullet)$ denoting the Gaussian kernel. $\mathcal{K}_\gamma(x_i, x)$ is a product kernel function of possibly continuous and discrete variables:

$$\mathcal{K}_\gamma(x_i, x_0) = \mathcal{K}_h(x_i^c, x_0^c) L_\lambda(x_i^d, x_0^d) , \tag{A9}$$

where $\mathcal{K}_h(\bullet)$ is the product kernel for C continuous variables derived from the Gaussian kernel. $L_\lambda(x_i^d, x_0^d)$ is the product kernel for D binary variables that is derived from the univariate kernel function introduced by Aitchison and Aitken (1976):

$$I(x_i^d, x_0^d, \lambda_d) = \begin{cases} 1 & \text{if } x_i^d = x_0^d \\ \lambda_d & \text{otherwise} , \end{cases} \tag{A10}$$

where the bandwidth $\lambda_d \in [0, 1]$. All bandwidth parameters are selected by the cross-validation algorithm explained in Appendix A.4.

A.4 Bandwidth selection algorithm

We select the bandwidth parameters in Eqs. A3, A5, and A7 by minimizing a least-squares cross-validation objective function. Given the large number of observations a cross-validation procedure using the full sample size is, however, computational infeasible in a reasonable amount of time. We therefore employ a variant of the efficient cross-validation algorithm outlined in Racine (1993). The algorithm is based on the observation that the optimal bandwidth for variable j with respect to the asymptotic mean integrated square error takes the form

$$h_{j,opt} = c_j \sigma_j N^\alpha , \tag{A11}$$

where σ_j is the variable's standard deviation and α is a known constant that depends on the kernel order and number of variables involved. The unknown scaling factor c depends in a non-trivial way on the kernel function and the underlying distribution function, see e.g. Härdle et al. (2004, Ch. 3). Exploiting the fact the scaling factor c does not depend on the sample size, leads to following bandwidth selection procedure:

1. Draw s ($s = 500$) subsamples of size n_s ($n_s = 500$) without replacement from the entire data set.

2. Find the optimal bandwidths and scaling factors for each subsample by minimizing the cross-validation criterion function via numerical search.

3. Compute the cross-validated bandwidths for the entire sample by replacing c_j in the formula for $h_{j,opt}$ with the median of the s scaling factors obtained in step 2.

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Table 1: Summary statistics for single-family houses by period of construction and half of the city. Mean of variables. Standard deviations of variables are in brackets. House price is transaction price for the bundle of building and land. Land value is prediction from fitted Eq. 14. Building value is house price net of land value. All prices and values are in thousand year 2000 Euros. Quality index per building is prediction from Eq. 13.

	(1)		(2)		(3)	
	before 1949		1949 to 1989		after 1989	
	West	East	West	East	West	East
Panel A: price and quality index						
House price	281.94	156.88	252.33	180.74	285.76	207.26
	[214.27]	[85.11]	[156.21]	[80.81]	[156.29]	[62.54]
Land value	162.39	84.39	132.24	99.22	75.11	47.15
	[140.53]	[46.32]	[114.81]	[50.35]	[77.75]	[23.13]
Building value	119.55	71.94	120.10	81.52	210.64	160.11
	[143.37]	[67.78]	[101.56]	[61.56]	[107.98]	[53.72]
Quality index	0.512	0.499	0.512	0.441	0.577	0.452
	[0.288]	[0.253]	[0.273]	[0.261]	[0.273]	[0.259]
Panel B: lot and floor size						
Floor size (in sqm)	155.68	137.19	142.87	141.71	163.06	132.93
	[69.36]	[60.16]	[49.94]	[58.83]	[38.78]	[39.58]
Lot size (in sqm)	616.90	705.60	556.84	828.82	373.58	394.91
	[347.96]	[339.23]	[296.33]	[328.49]	[214.42]	[215.90]
No of Observations	5,089	2,752	5,881	864	1,727	2,647

Table 2: Summary statistics for transacted residential sites. Number of observations is 20,754. Price is in year 2000 Euros. CBD is the Breitscheidplatz for Berlin's west half and the Alexanderplatz for the east half. The quality of neighborhood amenities is measured for each site with the expert-based rating provided by Berlin's Senate Department for Urban Development.

	Mean		Std. Dev.	Units
Panel A: price and continuous characteristics				
Price per sqm	160.23		105.00	Euro
Distance to CBD	12.48		3.97	Km
Panel B: amenity quality rating				
Low quality	38.34%	Medium quality		47.61%
High quality	14.05%			
Panel C: unusual features of lot				
Ground monument	0.52%	Lake side		2.10%
Demolished structure	36.04%	Land easement		21.03%
Panel D: recoupment charge for public infrastructure				
full charge	26.86%	reduced charge		26.63%
Panel E: business circumstances				
Non-private seller	28.58%	Non-private buyer		10.23%
Personal relations	6.34%	Other unusual		7.19%

Table 3: Wilcoxon rank-sum test on conditional distribution of quality index. Sample is divided by half of the city. Column (1) tests the null hypothesis that the quality measure has the same distribution in the west (q_W) and the east (q_E) half in the respective period. z-statistic reports the standardized Wilcoxon test-statistic: $z = (T - \frac{n_W(n+1)}{2})/(\frac{n_W n_E s^2}{n})^{-1/2}$, where T is the sum of ranks for the observations in the west half sample, n_j ($j \in \{West, East\}$) is the number of observations in each sample, n is the total number of observations, and s is the standard deviation of the combined ranks for both samples. P-value is for $N(0,1)$ distribution. Column (2) gives the probability that the quality of a building in the west half is larger than the quality of a building in the east half. P-value is calculated as $p = (T - (\frac{n_W(n_W+1)}{2}))/(n_W n_E))$, where T is the sum of ranks for the observations in the west sample.

	(1)		(2)		
	$\Pr(q_{\mathrm{W}} > q_{\mathrm{E}})$ $= \Pr(q_{\mathrm{W}} \leqslant q_{\mathrm{E}})$		$\Pr(q_{\mathrm{W}} > q_{\mathrm{E}})$	No of Obs.	
	z-Stat.	P-Value	P-Value	West	East
constructed before 1949	2.156	0.031	0.515	5,089	2,752
constructed 1949–1989	7.101	0.000	0.575	5,881	864
constructed after 1989	14.822	0.000	0.632	1,727	2,647

Table 4: Effect of amenity level on price of undeveloped land. Table reports OLS estimates of Eq. 16. CBD is the Breitscheidplatz for the west half and the Alexanderplatz for the east half. Clustered standard errors are reported in brackets. Clustering corrects for intra-district correlation of residuals. *** significant at 1%-level **significant at 5%-level *significant at 10%-level.

Dependent variable: ln land price per sqm				
Specification	(1)		(2)	
low amenity level	-0.100**	[0.036]	-0.089**	[0.032]
high amenity level	0.106**	[0.051]	0.078*	[0.045]
ln distance to CDB			-0.351***	[0.079]
Lake side			0.335***	[0.040]
Ground monument			-0.269**	[0.103]
Demolished structure			-0.121***	[0.020]
Land easement			0.020**	[0.009]
Full charge			-0.071**	[0.030]
Reduced charge			-0.047*	[0.024]
Non-private seller			-0.088***	[0.017]
Non-private buyer			0.068***	[0.018]
Personal relations			-0.218***	[0.024]
Unusual circumstance			0.003	[0.036]
District dummies	Yes		Yes	
Time dummies	Yes		Yes	
$\bar{R}^2$	0.513		0.568	
No of Observations	20,754		20,754	

Table 5: Moran's test for spatial autocorrelation of building qualities. Table reports least squares estimates of Eq. 17. z-statistic is for the null hypothesis that building quality is not spatially autocorrelated. E[λ] and V[λ] under the null are calculated according to the formulas in Anselin (1988, p 102). P-value is for $N(0,1)$ distribution.

Dependent variable: Demeaned quality index				
	$\widehat{\lambda}$	z-stat.	P-value	No of obs.
Panel A: Westberlin				
all	0.200	91.204	0.000	12,697
before 1949	0.296	63.553	0.000	5,089
1949–1989	0.134	31.211	0.000	5,881
after 1989	0.383	35.239	0.000	1,727
Panel B: Eastberlin				
all	0.151	39.446	0.000	6,263
before 1949	0.140	18.864	0.000	2,752
1949–1989	0.115	5.942	0.000	864
after 1989	0.223	28.679	0.000	2,647

Table 6: Effect of GDR period on quality of newly built houses.. Table reports OLS estimates of Eqs 18, 19, and 20; with pre-WWII as before and post-reunification as after. Each regression uses 12,215 observations. FH is fraction of housing stock in statistical area that has been constructed between 1949–1989. CBD is the Breitscheidplatz for the west half and the Alexanderplatz for the east half. Share of SPD votes is the district share of votes for the Social Democratic Party in *Reichstagswahl* of 1928 and *Bundestagswahl* of 1994. Clustered standard errors are reported in brackets. Clustering corrects for intra-statistical area correlation. *** significant at 1%-level ** significant at 5%-level * significant at 10%-level.

Specification	(1)	(2)	(3)	(4)	(5)	(6)
D^{After}	0.132***	0.327*	0.114***	0.323*	-0.033	0.173
	[0.024]	[0.166]	[0.024]	[0.170]	[0.074]	[0.157]
$D^{East} \times D^{After}$	-0.161***	-0.168***			0.015	0.054
	[0.029]	[0.028]			[0.078]	[0.080]
$D^{East} \times D^{After} \times FH$			-0.370***	-0.393***		
			[0.104]	[0.103]		
D^{FH}					-0.535***	-0.585***
					[0.075]	[0.080]
$D^{FH} \times D^{After}$					0.167**	0.206***
					[0.078]	[0.073]
$D^{FH} \times D^{East}$					-0.193***	0.159
					[0.001]	[0.145]
$D^{FH} \times D^{East} \times D^{After}$					-0.185**	-0.237***
					[0.084]	[0.082]
Lake side		0.148***		0.152***		0.149***
		[0.037]		[0.038]		[0.037]
ln distance to CBD		-0.217***		-0.211***		-0.217***
		[0.078]		[0.079]		[0.078]
Share of SPD votes		-0.006		-0.006		-0.007
		[0.005]		[0.005]		[0.005]
Statistical area dummies	Yes	Yes	Yes	Yes	Yes	Yes
$\bar{R}^2$	0.185	0.193	0.181	0.189	0.185	0.194

Table A1: Least squares estimate of parametric effect on land price. Table reports estimates of the parametric part of the partial linear model given in Eq. 14. Standard errors are reported in brackets. R^2 is calculated for the overall fit of partial linear model. *** significant at 1%-level ** significant at 5%-level * significant at 10%-level.

Dependent variable: ln land price		
Ground monument	-0.270***	[0.036]
Demolished structure	0.035***	[0.005]
Land easement	-0.110***	[0.006]
Full recoupment charge	-0.042***	[0.007]
Partial recoupment charge	-0.044***	[0.006]
Non-private seller	-0.063***	[0.005]
Non-private buyer	0.094***	[0.008]
Unusual circumstances	-0.028***	[0.009]
Personal circumstances	-0.164***	[0.010]
No of observations	20,754	
R^2	0.879	

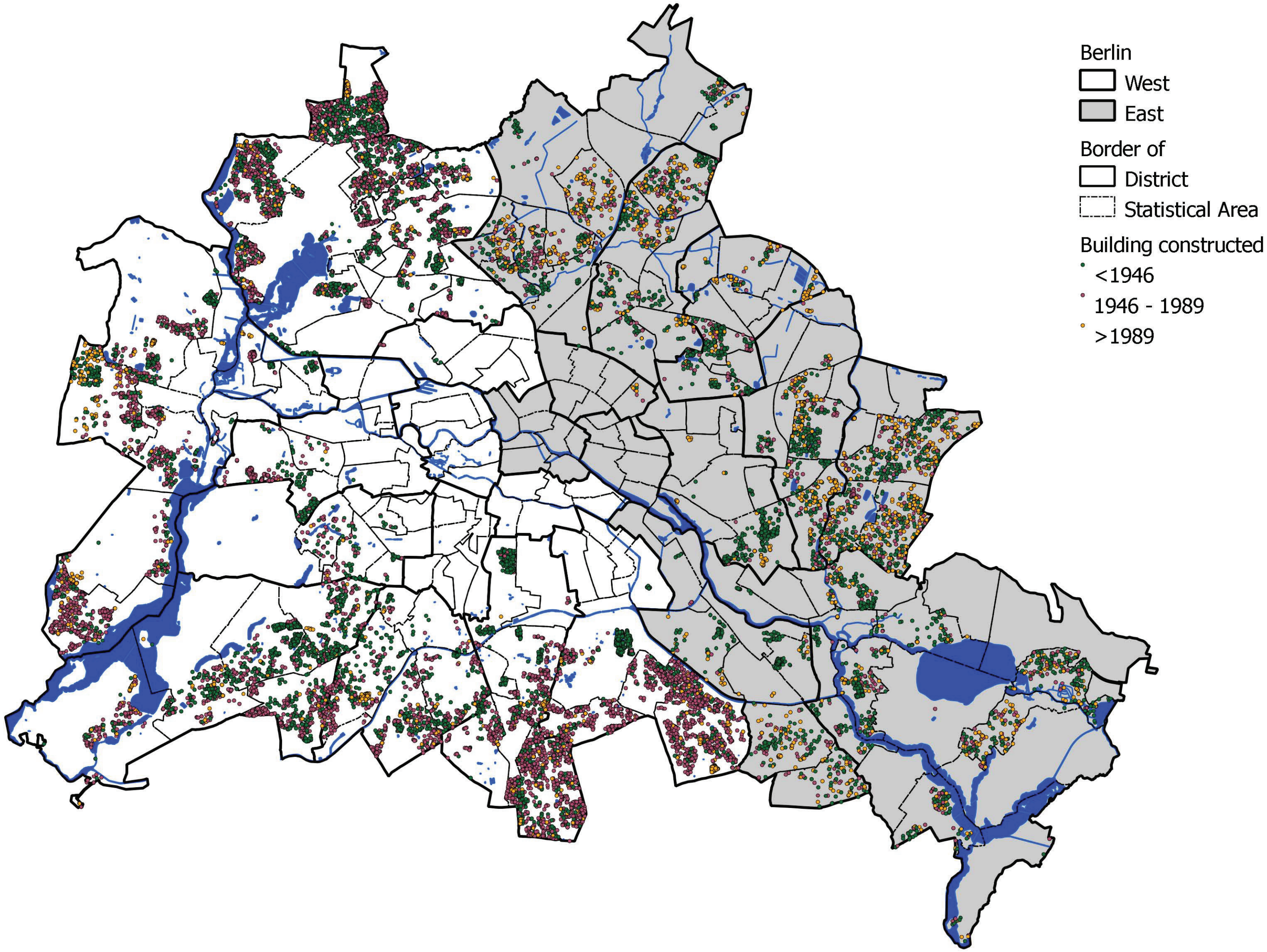

Figure 1: Map of Berlin and locations of single-family buildings. Berlin's borders have been unchanged effectively since 1920. The city covers an area of 891 sqms., the maximal extension in west-to-east direction is 45 km. Greyly shaded area is east half of Berlin, which was the capital of the GDR between 1949-1989. Thick black lines represent the 23 administrative districts as of 1990. Dashed black lines represent the 195 statistical areas. Blue areas are river and lakes. Circles indicate the locations of the 18,961 single-family houses transacted during the period 1996-2008.

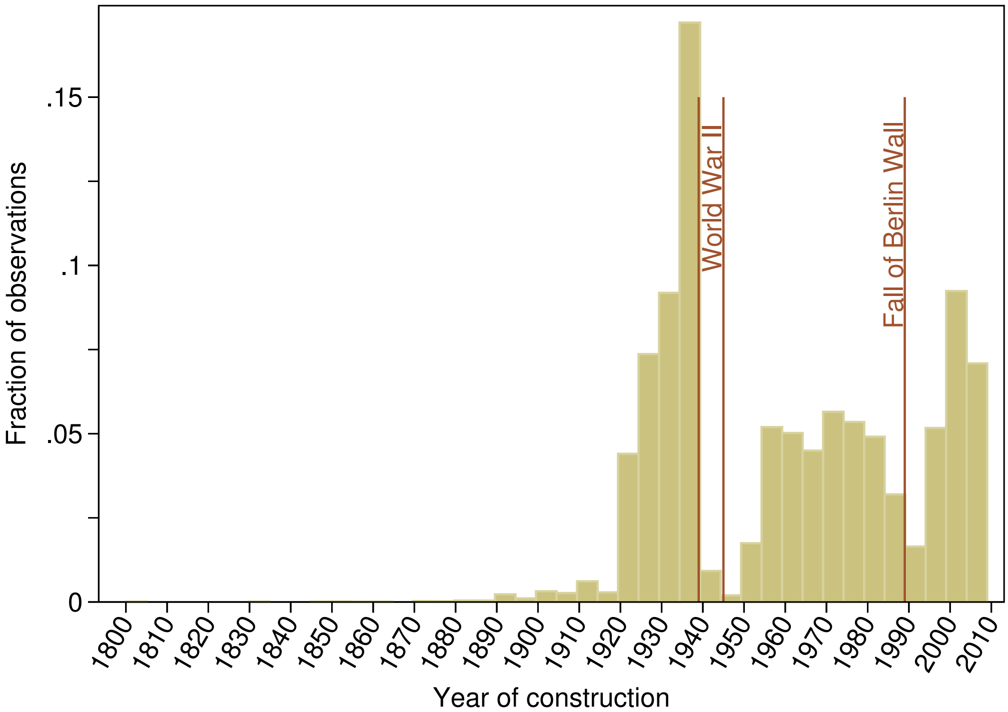

Figure 2: Histogram of year of construction. 18,961 single-family house transactions that occurred in Berlin between 1996–2008. World War II lasted from 1939 to 1945. The fall of the Berlin Wall took place in 1989.

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